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CERAMIC MATERIALS BASED ON SILICON-CONTAINING MINERAL RAW MATERIAL

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The possibility of using silicon-containing mineral raw material (quartz sand and sandy opoka) mined in the Belgorod region for manufacturing ceramic materials with a combination of high thermostability and satisfactory mechanical compressive strength was demonstrated.

Key words: ceramic, mineral raw material, cold isostatic molding.

For complex and maximum utilization of the mineral raw-materials base, production of ceramic materials from industrial wastes from the metallurgical and mining industries is of interest [1 – 3]. The economic potential of the Belgorod region is due to natural resources to a great degree, including iron ore and chalk, which are in the greatest demand. However, silicon-containing mineral raw material revealed in mining bedrock is now used for production of different types of ceramic materials for the purpose of more rational utilization of developed deposits and due to the shrinking reserves of traditional ceramic raw material.

We investigated the potential possibility of utilizing silicon-containing mineral raw material — quartz sand and sandy opoka mined in the Belgorod region, for production of ceramic materials and articles made from them.

The quartz sand deposits investigated here are of the alluvial geological-industrial type and have a depth of 2.0 – 5.0 m. The depth of the stripping rock for extracting such sand reaches 7.0 m. Most of the sand in the initial state is represented by the 0.1 – 0.315 mm fraction (80 – 85%), and there are no powdery or clay particles. The results of x-ray phase analysis (Rigaku Ultima IV diffractometer) and micro-x-ray-spectral analysis (Quanta 200 3D electron microscope), established the following composition of the quartz sand (%):[4] 1.68 Al_2O_3, 97.28 SiO_2, 0.41 CaO, 0.62 Fe_2O_3. Note that the SiO_2 content is greater than 96%, which is higher than the values defined by GOST 7031–75 and TU 39-0147001, which regulate the requirements for the quality of quartz sand for fabrication of thin ceramics and refractories. In studying the initial sand with an OLYMPUS GX51 optical microscope, we found that the quartz is of the water-transparent variety (rock crystal) with no inclusions of other minerals. The white color obtained due to the surface roughness of the quartz grains is a special feature of the investigated quartz sand.

Sandy opoka is a hard, flinty, sedimentary rock that basically consists of microgranular, aqueous, amorphous, muddy grey silica. Opoka is stripping rock in mining of chalk. The depth of the deep-lying layers is 8 – 12 m. The composition of sandy opoka is represented by oxides (%): 7.63 Al_2O_3, 68.38 SiO_2, 9.96 CaO, 9.33 F_2O_3, 3.64 K_2O, 1.31 TiO_3, 1.21 P_2O_5, 0.83 MgO.

We know that the properties of ceramic articles are a function of the quality of the powders of the initial components used to make them to a great degree [4]. Grinding of the powders, which crushes the powder particles to the required size, attaining the corresponding granulometric composition of the powder, and activating sintering of the ceramic by mechanical activation of the powder are an important stage in fabrication of powders for subsequent compacting and sintering of the ceramic article.

The initial quartz sand and sandy opoka were ground in the present study in a vibration-cavitation mill with a steel grinding assembly for 1 h. The studies of the particle size distributions of the quartz sand powder and the sandy opoka powder after grinding, conducted with an Analysette 22 NanoTec laser diffraction particle size analyzer, showed that the granulometric composition of the quartz sand powder particles is characterized by two basic fractions corresponding to the ranges 1 – 4 μm (about 50%) and 5 – 12 μm (about 35%) (Fig. 1*a*), while the particle distribution in the sandy opoka powder has three basic fractions: 1 – 5 μm (about

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[4] Here and below — content by weight.

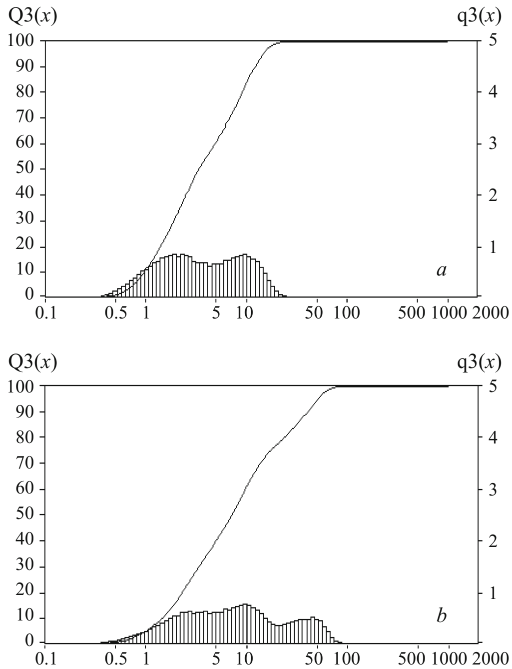

Fig. 1. Particle size distribution of powder after grinding: *a*) quartz sand; *b*) sandy opoka.

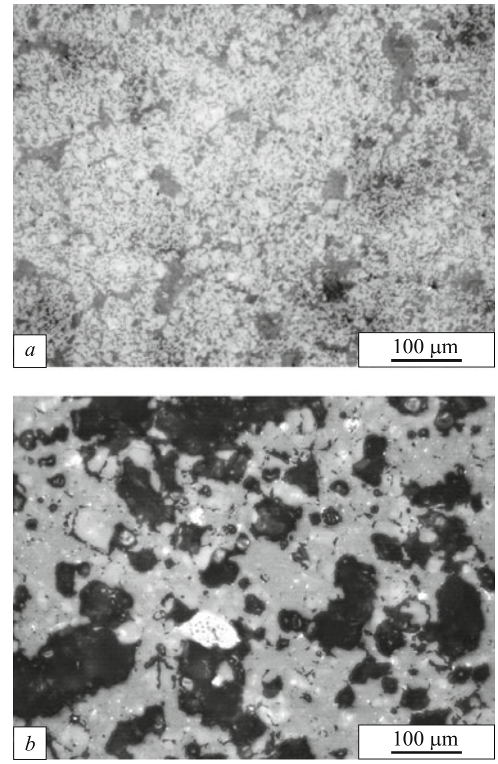

Fig. 2. Surface of ceramic made of quartz sand (*a*) and sandy opoka (*b*).

35%), 7 – 20 μm (about 38%), and 30 – 60 μm (about 20%) (Fig. 1*b*).

These powdered materials were molded after grinding by the method of cold isostatic molding [5] at a pressure of 250 MPa using an EPSI CIP 400-200*1000Y press. This method produces mechanically strong semiproducts of complex shape close to the final shape of the article with a high density (up to 675% of the theoretical density for ceramics and up to 100% for metals) and with no mechanical stresses in them.

The sintering temperature of the compacted materials was determined by dilatometric analysis (DIL 402 C/4/G high-temperature dilatometer); it was 1350°C for the quartz sand ceramic and 1200°C for the sandy opoka ceramic. Sintering was conducted in atmospheric air for 5 h.

The open porosity and compressive strength were determined for the ceramic materials obtained. The porosity was estimated by analyzing the granulometric composition of the pores using images of previously polished surfaces obtained with an OLYMPUS GX51 optical microscope (Fig. 2).

The ceramic made from sandy opoka has much higher open porosity in comparison to the quartz sand ceramic. This difference could be due to the different granulometric composition of the powders used for fabricating the ceramics. In the case of the quartz sand powder, the particles were only distributed in two fractions, the corresponding particle sizes in the fractions did not differ very significantly (minimum particle size of fine fraction of 1 μm, maximum size of coarse fraction of 12 μm). The sandy opoka powder was distributed in three basic fractions in which the particle sizes differed very strongly (from 1 μm for the fine fraction to 60 μm for the coarse fraction). In contrast to the sandy opoka powder, the more homogeneous granulometric composition characteristic of the quartz sand powder provided for better filling of the mold with a minimum number of cavities and consequently production of high-density and low-porosity semiproduct after compacting by cold isostatic molding. The estimation of the porosity of the ceramic samples obtained by analysis of the granulometric composition of the pores was 2% for quartz sand ceramics and 33% for sandy opoka ceramics.

The compressive strength of the ceramic materials obtained, determined in an Instron 5882 universal testing machine according to GOST 473.6–81, was 159 MPa for the quartz sand ceramic and 137 MPa for the sandy opoka ceramic. Such mechanical strength values are higher than the compressive mechanical strength of quartz ceramic fabricated by casting (50 – 80 MPa) and are totally satisfactory if no special requirements are imposed for the mechanical properties of the ceramic articles during use.

Using quartz sand and sandy opoka mined in the Belgorod region as initial raw material for production of ceramics thus allows obtaining ceramic materials with a satisfactory combination of thermostability and mechanical strength which, given the availability and low cost of the initial raw material, and if the technology is further optimized, will allow drawing a conclusion concerning the potential of using

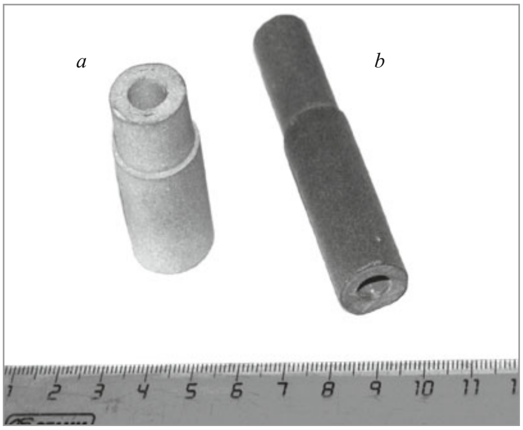

Fig. 3. Experimental items made of ceramic materials based on: *a*) quartz sand powder; *b*) sandy opoka powder.

such ceramics for manufacturing articles for electrical engineering, vacuum technology, construction parts, etc. Experimental ceramic articles fabricated from quartz sand powder (see Fig. 3*a*) and sandy opoka powder (see Fig. 3*b*) are shown in Fig. 3 as an example.

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